

# Historical record of a sauropod (Dinosauria: Titanosauria) specimen at the Museo Seminario Valparaíso: The first dinosaur discovery of Chile?

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Recibido: 26 de septiembre 2025 - Aceptado: 8 de diciembre 2025 - Publicado: 13 de marzo 2026

**Para citar este artículo:** Omar Vicencio-Campos, Luis Chirino-Gálvez, Jhonatan Alarcón-Muñoz, Antonia Atisha, & Agustín G. Martinelli (2026). Historical record of a sauropod (Dinosauria: Titanosauria) specimen at the Museo Seminario Valparaíso: The first dinosaur discovery of Chile?. *Publicación Electrónica de la Asociación Paleontológica Argentina* 26(1): 113–128.

**Link a este artículo:** <http://dx.doi.org/10.5710/PEAPA.08.12.2025.555>

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# HISTORICAL RECORD OF A SAUROPOD (DINOSAURIA: TITANOSAURIA) SPECIMEN AT THE MUSEO SEMINARIO VALPARAÍSO: THE FIRST DINOSAUR DISCOVERY OF CHILE?

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**Abstract.** Since its founding in 1870, the Colegio Seminario San Rafael of Valparaíso has offered natural science-related courses, complemented by laboratory work. Thus, in 1881, five science "cabinets" were established within the school premises, and in 1886, the building that still houses them was inaugurated. The Museo Seminario Valparaíso (MSV) houses various natural history collections, among which a notable paleontological collection stands out, comprising paleobotanical, invertebrate, and vertebrate specimens. Within one of the oldest mineral collection showcases, associated with copper oxides and sulfides samples, a proximal fragment of a right sauropod ulna was found. This ulna must have been deposited long ago, which is proven when it is considered that the associated mineral specimens with collection register labels on the shelf dates between 1860 and 1896, and because this collection has not been modified and it has remained unchanged for over a century. On the other hand, it was only in the 1960s that the first formal descriptions of dinosaur bone records in Chile were made, based on indeterminate titanosaur remains from the informal unit "*Estratos de Quebrada La Totorá*". Morphological comparisons of the ulna suggest affinities with the clade Titanosauria. Furthermore, based on its preservation characteristics, the provenance of the specimen is attributed to the *Estratos de Quebrada La Totorá*, Coquimbo region. In this way, the specimen could represent the first discovery of a non-avian dinosaur in Chile and the first historical evidence of titanosaurs found in a Chilean museum collection.

**Key words.** Sauropoda. Titanosauria. Paleontology. Valparaíso. Seminario San Rafael. Chile.

**Resumen.** REGISTRO HISTÓRICO DE UN ESPECIMEN DE SAURÓPODO (DINOSAURIA: TITANOSAURIA) DEL MUSEO SEMINARIO VALPARAÍSO: ¿EL PRIMER DESCUBRIMIENTO DE UN DINOSAURIO DE CHILE?. Desde su fundación en 1870, el Colegio Seminario San Rafael de Valparaíso dicta asignaturas asociadas a las ciencias naturales, las cuales se complementan con trabajo de laboratorio. Así, en 1881 se establecieron cinco "gabinetes" de ciencias en las dependencias del colegio y en 1886 se inauguró el edificio que los alberga hasta nuestros días. El Museo Seminario Valparaíso (MSV) posee diversas colecciones de historia natural, destacando una pequeña colección paleontológica con especímenes paleobotánicos, invertebrados y vertebrados. Entre la colección más antigua de minerales, asociados a óxidos y sulfuros de cobre, se halló un fragmento proximal de una ulna derecha de saurópodo. Esta ulna debió ser depositada durante fines del siglo 19, considerando que la colección de minerales data de entre 1860 a 1896, y no ha sido intervenida en más de un siglo. Por otro lado, recién en la década de 1960 se describieron formalmente los primeros registros óseos de dinosaurios en Chile, hallados en la unidad informal "*Estratos de Quebrada La Totorá*", que fueron atribuidos a titanosaurios indeterminados. Comparaciones morfológicas del espécimen aquí descrito sugieren que presenta afinidades con el clado Titanosauria. Además, en base a las características de su preservación, la procedencia del espécimen se atribuye a los Estratos de Quebrada La Totorá, en la región de Coquimbo. De esta manera, la ulna descrita aquí podría representar el primer descubrimiento de un dinosaurio no aviano en Chile y la primera evidencia histórica de titanosaurios hallada en una colección de museo en Chile.

**Palabras clave.** Sauropoda. Titanosauria. Paleontología. Valparaíso. Seminario San Rafael. Chile.

## INTRODUCTION

### Historical context of dinosaurs in Chile

The South American fossil record of non-avian dinosaurs

is abundant and diverse, with most findings coming from Argentina and Brazil, while the first record of ichnites from South America comes from Colombia (e.g., Bonaparte, 1996;

Novas, 2009; González Riga et al., 2016; Otero et al., 2020; Tomaselli et al., 2021; Fiorelli et al., 2022). These published records include both skeletal remains and ichnites (footprints), providing significant insights about the diversity, evolution, and historical biogeography of South American dinosaurs during the Mesozoic Era (e.g., Bonaparte, 1996, 2007; Calvo & Bonaparte, 1991; Novas et al., 2005, 2015; Calvo et al., 2007; Novas, 2009; González Riga et al., 2016; Hechenleitner et al., 2020; Otero et al., 2020; Tomaselli et al., 2021; Fiorelli et al., 2022).

The earlier South American dinosaur fossils are fragmentary remains discovered in northeast Brazil between 1859 and 1906, initially considered lost and later rediscovered at the Natural History Museum in London (Kellner & Campos, 2000; Bandeira et al., 2024), and since 1882, bone specimens collected in Argentina (Lambert & Data Information Group, 1990; Gasparini et al., 2007). Even though these first discoveries from Argentina were also fragmentary specimens, they were reported early on and referred to as distinctive new genera of sauropod dinosaurs (Lydekker, 1893; Ameghino, 1898).

In contrast to Brazil and Argentina, Chile has relatively few dinosaur fossil discoveries. The first published account on non-avian dinosaur skeletal remains in Chile date back to the 1960s, when fossil bones referred to Titanosauridae were found. These bones consist of: a right humerus, an incomplete caudal vertebra centrum, a left scapulocoracoid portion, and rib fragments, discovered in the locality of Pichasca, Coquimbo Region, specifically in Upper Cretaceous rocks attributed to the Viñita Formation at that time (Casamiquela et al., 1969). This unit, initially defined by Aguirre and Egert (1965), was divided into three members; however, it was later modified by Emparan and Pineda (1999), redefining the lower two members as the "*Estratos de Quebrada La Totora*". This geological unit corresponds to a continental sedimentary sequence of Middle Albian–Cenomanian age (Emparan & Pineda, 1999; Pineda & Emparan, 2006).

In the following years, new dinosaur remains were discovered, although most of them were too fragmentary to determine their taxonomic affinities, phylogenetic relationships, and biogeographic significance (Figs. 1A, B; Tab. 1). It was not until the 21<sup>st</sup> century that the first bony

dinosaur species was formally described in Chile. This dinosaur was the titanosaurian sauropod *Atacamatitan chilensis* Kellner et al., 2011, based on axial and appendicular remains. Its record comes from the Antofagasta Region, specifically from the Tolar Formation, a unit composed of reddish-brown and gray conglomerates, red sandstones and siltstones, together with an ignimbrite ash tuff of Late Cretaceous age (Kellner et al., 2011; Tomlinson et al., 2018). Subsequently, *Chilesaurus diegosuarezi* Novas et al., 2015 was described, a peculiar theropod dinosaur found in Upper Jurassic rocks of the Toqui Formation, composed of calcareous tuffaceous sandstones, coquinoïd sandy limestones, and pyroclastic breccias, in the Aysén Region (De la Cruz et al., 2003; Novas et al., 2015). A few years later, the titanosaurian sauropod *Arackar licanantay* Rubilar-Rogers et al., 2021 was described, based on axial and appendicular elements recovered from deposits of the Late Cretaceous Hornitos Formation, a unit composed of red sandstones, yellowish calcareous mudstones, limestones, whitish tuff levels, and matrix-supported breccias and conglomerates outcropping in the Atacama Region (Arévalo, 2005).

The Late Cretaceous rocks of the Dorotea Formation, composed of greenish-gray and reddish-brown sandstones with abundant conglomerate lenses and siltstones, thin layers of sandy calcareous concretions, and mudstones (Schwartz et al., 2016; George et al., 2020) in the Magallanes Region, southern Chile, have yielded several dinosaur findings (see Tab. 1). One of the most remarkable discoveries is the partial skeleton of an ankylosaurian dinosaur named *Stegouros elengassen* Soto-Acuña et al., 2021. This dinosaur possessed a highly distinctive tail weapon composed of osteoderms covering the caudal vertebrae, forming a flat structure resembling the Aztec weapon known as macuahuitl (Soto-Acuña et al., 2021). The phylogenetic analyses conducted by Soto-Acuña et al. (2021) led to the recognition of a new clade of Gondwanan ankylosaurs, the Parankylosauria. Another significant discovery is an ornithischian dinosaur of the clade Hadrosauroidea, named *Gonkoken nanoi* Alarcón-Muñoz et al., 2023. Its phylogenetic position suggests that it does not belong to Hadrosauridae, unlike other South American hadrosauroids, a conclusion supported by its combination of plesiomorphic and derived traits (Alarcón-Muñoz et al., 2023).

### The Museo Seminario Valparaíso (MSV)

The Seminario San Rafael School, founded in 1870, is located in the city of Valparaíso and in the region of the same name. Currently, it houses several natural science cabinets established in 1881, including collections acquired in Europe and from different parts of Chile. A few years later, these cabinets were moved to a new museum building, inaugurated in 1886, where the collections have been housed ever since (Fig. 2A). The collections preserved in this building have remained untouched for over a century, with no new materials added due to changes occurring in Chilean education programs through the 20<sup>th</sup> century (Chirino & Vicencio, 2021; Chirino-Gálvez et al., 2022) driving to the closure of school museum cabinets throughout much of Chile.

The cabinets of the Museo Seminario Valparaíso (hereafter MSV) preserve malacological, mastozoological, ornithological, archaeological, and mineralogical collections (Chirino & Vicencio, 2021; Chirino-Gálvez et al., 2022; Valenzuela Matus & Chirino-Gálvez, 2023; Figueroa & Chirino-Gálvez, 2025). The mineralogical collection includes a small paleontological sample composed of paleobotanical specimens, as well as invertebrate and vertebrate fossils found both within Chilean territory and abroad, which are being studied and assessed for educational purposes (Chirino & Vicencio, 2021, 2022; Chirino-Gálvez et al., 2022, 2023).

During a review of the display showcases of the mineralogical collection section (Figs. 2B, 2C) conducted in 2021, a large proximal fragment of a right sauropod ulna was found on a dusty shelf (Fig. 2D), associated with large copper oxides and sulfides rock samples from northern Chile. The specimen lacked a registration record or any other source of information to determine its precise origin (Chirino & Vicencio, 2022; Chirino-Gálvez et al., 2022). However, the registration labels on the accompanying minerals indicate that this collection dates between 1860 and 1896, with all



**Figure 1.** A, Satellite image of southern South America showing the location of Chile (Landsat/Copernicus 2020 image; Google Earth, accessed September 2025). B, Map of Chile showing the geographical distribution of dinosaurs based on osteological specimens. 1, Sauropoda indet., *Atacamititan chilensis* (Tolar Formation, Late Cretaceous). 2, Sauropoda indet. (Strata of Quebrada Blanca, Late Cretaceous). 3, Titanosauria indet. (Pajonales Formation, Late Cretaceous). 4, Sauropoda indet. (Quebrada Monardes Formation, Early Cretaceous). 5, Titanosauria indet., *Lithostrotia* indet., *Arackar licanantay* (Hornitos Formation, Late Cretaceous). 6, Titanosauria indet., Abelisauridae indet. (*Estratos de Quebrada La Titora*, Late Cretaceous). 7, Dinosauria indet. (Las Chilcas Formation, Late Cretaceous). 8, Sauropoda indet., Diplodocidae indet., Diplodocinae indet., Titanosauriformes? indet., *Chilesaurus diegosuarezi* (Toqui Formation, Late Jurassic). 9, cf. Ornithopoda indet., *Stegouros elengassen*, *Gonkoken nanoi*, Theropoda indet., (?) Unenlagiinae indet., Unenlagiinae indet. (Dorotea Formation, Late Cretaceous). Scale= 1000 km.

**TABLE 1. Osteological record of non-avian dinosaurs from Chile.**

Taxonomic identification	Higher taxon	Material	Provenance	Geological Unit	Age	Reference
Sauropoda indet.	Sauropoda (Titanosauriformes)	right femur, dorsal vertebrae, and a portion of a humerus	Quebrada Cortadera, Antofagasta Region	Tolar Formation	Maastrichtian	Rubilar-Rogers (2005)
<i>Atacamitan chilensis</i>	Sauropoda (Titanosauria)	partial skeleton	Near Conchi Viejo, Antofagasta Region	Tolar Formation	Maastrichtian	Kellner et al. (2011)
Sauropoda indet.	Sauropoda	"a large bone"	Quebrada Blanca, Antofagasta Region	Strata of Quebrada Blanca	Late Cretaceous	Salinas et al. (1991)
Titanosauria indet.	Sauropoda (Titanosauria)	several big, long bones	Quebrada Pajonales, Antofagasta Region	Pajonales Formation	Maastrichtian	Salinas et al. (1991)
Iguanodontia indet.	Ornithopoda (Iguanodontia)	caudal centrum	Cerro La Isla, Atacama Region	Quebrada Monardes Formation	Berriasian?	Bell & Suárez (1989), Alarcón-Muñoz et al. (2025)
Sauropoda indet.	Sauropoda	fragment of a possible ulna or fibula	Cerro La Isla, Atacama Region	Quebrada Monardes Formation	Berriasian?	Bell & Suárez (1989)
Titanosauria indet.	Sauropoda (Titanosauria)	a portion of left humerus and rib fragments	Cerro Algarrobito, Atacama Region	Hornitos Formation	Campanian–Maastrichtian	Chong (1985), Rubilar-Rogers et al. (2012)
Lithostrotia indet.	Sauropoda (Titanosauria)	caudal centrum	Quebrada La Higuera, southeast Copiapó, Atacama Region	Hornitos Formation	Campanian–Maastrichtian	Rubilar-Rogers et al. (2017)
<i>Arackar licanantay</i>	Sauropoda (Titanosauria)	partial skeleton	La Higuera ravine, Copiapó, Atacama Region	Hornitos Formation	Campanian–Maastrichtian	Rubilar-Rogers et al. (2021)
Titanosauria indet.	Sauropoda (Titanosauria)	a proximal portion of a right humerus, a fragment of a left scapuloco-racoid, rib fragments, an ischium fragment, an incomplete metapodial, and an incomplete caudal centrum	Pichasca Natural Monument, north San Pedro, Hurtado River valley, Coquimbo Region	Estratos de Quebrada La Totora	Albian–Turonian	Casamiquela et al. (1969)
Titanosauria indet.	Sauropoda (Titanosauria)	an anterior half of a dorsal vertebra	Pichasca Natural Monument, north San Pedro, Hurtado River valley, Coquimbo Region	Estratos de Quebrada La Totora	Albian–Turonian	Vargas et al. (2000)
Titanosauria indet.	Sauropoda (Titanosauria)	two teeth	Pichasca Natural Monument, north San Pedro, Hurtado River valley, Coquimbo Region	Estratos de Quebrada La Totora	Albian–Turonian	Salinas et al. (1991), Rubilar-Rogers (2003)
Abelisauridae indet.	Theropoda (Abelisauridae)	isolated lateral tooth	Pichasca Natural Monument, north San Pedro, Hurtado River valley, Coquimbo Region	Estratos de Quebrada La Totora	Albian–Turonian	Amudeo-Plaza et al. (2023)

TABLE 1. Continuation.

Taxonomic identification	Higher taxon	Material	Provenance	Geological Unit	Age	Reference
Dinosauria indet.	Dinosauria	"bones of big dinosaurs"	Cerro Negro and Cerro Mesa, Valparaíso Region	Las Chilcas Formation	Aptian?–Albian	Salinas et al. (1991)
Sauropoda indet.	Sauropoda	mid or posterior dorsal vertebra	Mallín Grande, Chile Chico, Aysén region	Toqui Formation	late Tithonian	Salgado et al. (2015)
Sauropoda indet.	Sauropoda	two mid? caudal vertebrae	Mallín Grande, Chile Chico, Aysén region	Toqui Formation	late Tithonian	Salgado et al. (2015)
Sauropoda indet.	Sauropoda	partial sternal plate	Mallín Grande, Chile Chico, Aysén region	Toqui Formation	late Tithonian	Salgado et al. (2015)
Diplodocidae indet.	Sauropoda (Diplodocoidea)	middle? cervical centrum	Mallín Grande, Chile Chico, Aysén region	Toqui Formation	late Tithonian	Salgado et al. (2015)
Diplodocinae indet.	Sauropoda (Diplodocoidea)	incomplete mid-posterior caudal vertebra	Mallín Grande, Chile Chico, Aysén region	Toqui Formation	late Tithonian	Salgado et al. (2015)
Titanosauriformes? indet.	Sauropoda (Titanosauriformes)	a distal end of a left femur	Mallín Grande, Chile Chico, Aysén region	Toqui Formation	late Tithonian	Salgado et al. (2015)
Titanosauriformes? indet.	Sauropoda (Titanosauriformes)	a distal end of a right tibia	Mallín Grande, Chile Chico, Aysén region	Toqui Formation	late Tithonian	Salgado et al. (2015)
<i>Chilesaurus diegosuarezi</i>	Theropoda (Tetanurae)	several individuals of different degrees of completeness	Mallín Grande, Chile Chico, Aysén region	Toqui Formation	late Tithonian	Novas et al. (2015)
cf. Ornithopoda indet.	?Ornithopoda	middle caudal centrum	Sierra Baguales, Magallanes Region	Dorotea Formation	early Maastrichtian	Rubilar-Rogers et al. (2013)
<i>Stegouros elengassen</i>	Ankylosauria (Parankylosauria)	an almost complete skeleton	Mammal Quarry, Rio de Las Chinas Valley, Magallanes Region	Dorotea Formation	late Campanian–early Maastrichtian	Soto-Acuña et al. (2021)
<i>Gonkoken nanoi</i>	Ornithopoda (Hadrosauridae)	bones of several individuals	Loma Koken, Rio de Las Chinas Valley, Magallanes Region	Dorotea Formation	late Campanian–early Maastrichtian	Alarcón-Muñoz et al. (2023)
Theropoda indet.	Theropoda	incomplete tibia	Locality SC3, Las Chinas Valley, Magallanes Region	Dorotea Formation	late Campanian–early Maastrichtian	Davis et al. (2023)
Megaraptoridae indet.	Theropoda (Megaraptoridae)	isolated teeth	Localities SC1 and SC2, Las Chinas Valley, Magallanes Region	Dorotea Formation	late Campanian–early Maastrichtian	Davis et al. (2023)
(?) Unenlagiinae indet.	Theropoda (Dromaeosauridae)	isolated teeth	Localities SC1, Las Chinas Valley, Magallanes Region	Dorotea Formation	late Campanian–early Maastrichtian	Davis et al. (2023)
Unenlagiinae indet.	Theropoda (Dromaeosauridae)	isolated tooth and partial pedal ungual phalanx	Locality SC2, Las Chinas	Dorotea Formation	late Campanian–early Maastrichtian	Davis et al. (2023)



**Figure 2.** A, Photo of the building where the Museo Seminario Valparaiso (MSV) collections are housed. B, Mineral collection present at the MSV. C, View of the ulna fragment (MSVP19-3.1.1) along with copper minerals during its discovery in 2021. D, position of the ulna fragment in a sauropod dinosaur. Scale= 60 cm.

specimens coming from northern Chile. This information suggests that the ulna may also have been deposited in the mineralogical collection in the late 19th century, where it has remained ever since.

In this work, we report the discovery of an incomplete right ulna from a sauropod dinosaur. The specimen was identified within the historical collection of the MSV and has likely remained at this institution since the late 19th century. The objective of this study is to determine the possible origin of the sauropod ulna from the MSV. In addition, it aims to determine the possible taxonomic affinities of the specimen, assessing whether it may be related to other titanosaurs from Chile and the rest of South America. Ultimately, it aims to contribute to the enhancement of the historical collections at the MSV.

## MATERIALS AND METHODS

Historically, Wolffsohn (1921) used the acronyms SV to refer to the osteological collections of the Seminario de Valparaíso repository. As no subsequent catalogs have been published for these collections, this designation has been adapted and formalized as MSV (Museo Seminario Valparaíso) for cataloging the institution's current collections (Chirino-Gálvez et al., 2022).

A thorough review of all historical records of the MSV was conducted to gather data that could help identify the origin of the material, with special emphasis on the records of the mineral and paleontology collections of the MSV. The analysis was carried out to confirm or rule out any historical background of the specimen: MSV.P19-3.1.1, proximal portion of the right ulna. In the present study, a detailed analysis of the specimen was performed using a classical macroscopic approach. This specimen was briefly mentioned by Vicencio Campos et al. (2024) in an abstract for a conference meeting, where its morphological features were preliminarily assessed. The taxonomic identification of the specimen was guided by comparisons with the literature on sauropods and direct comparison with the right ulna of *Saltasaurus loricatus* Bonaparte and Powell, 1980 (PVL 4017-74).

The provenance of the specimen was assessed through a macroscopic examination of its patina, following Turner-Walker (1993), who reported that preservation colors cor-

respond to specific mineral compositions. Based on these observations, lithological data documenting the presence of particular minerals in formations with established fossil records (Tab. 1) were used to infer the likely provenance of the specimen.

**Institutional Abbreviations.** **AODF**, Australian Age of Dinosaurs Fossil, Winton, Queensland, Australia; **FMNH PR**, Field Museum of Natural History, Chicago, USA; **MLP-CS**, Museo de La Plata, Cinco Saltos Collection, La Plata, Argentina; **MNHN**, Muséum national d'Histoire naturelle, Paris, France; **MPEF-PV**, Museo Paleontológico 'Egidio Feruglio', Paleontología de Vertebrados, Trelew, Chubut, Argentina; **MPM-PV**, Museo Regional Provincial Padre Manuel Jesús Molina, Paleontología de Vertebrados, Río Gallegos, Argentina; **MSV**, Museo Seminario Valparaíso, Valparaíso, Chile; **MSV.P**, Museo Seminario Valparaíso, Colección de Paleontología, Valparaíso, Chile; **NHMUK**, The Natural History Museum, London, UK; **PVL**, Colección de Paleontología de Vertebrados, Instituto Miguel Lillo, Tucumán, Argentina.

## RESULTS

### Collections

This unlabeled fossil bone was rediscovered mixed within the historical mineralogical collection, rather than with the fossil collection, which is housed in the malacological cabinet located in another hall. The mineralogical collection of the Museo Seminario Valparaíso is classified according to its origin and age. The oldest specimens correspond to a European-origin collection dating back to 1880. This collection was complemented by several local donations of different sizes, which include minerals such as oxides, sulfides, native minerals, and non-metallic minerals, among others. These specimens are displayed in four showcases—one central and three laterals—whose donors have been mentioned in documents such as the *Boletín Minero* of the National Mining Society. Some specimens retain their original labels; however, no donation with dated labels recorded beyond 1896 was present (SONAMI, 1883-1918; Chirino-Gálvez et al., 2022).

Among the MSV mineralogical collections obtained through donations, some fossils were identified and reevaluated. This allowed the identification of 18 fossil

wood specimens (Chirino-Gálvez et al., 2023) and the discovery of the incomplete dinosaur ulna, cataloged as MSV.P19-3.1.1. These specimens were incorporated into the local paleontological collection showcase, which also includes an ammonite from Cajón del Maipo and a third molar of a gomphoteriid (Oliver-Schneider, 1926; Chirino-Gálvez et al., 2022). Additionally, the paleontological collection primarily consists of invertebrate fossils of exotic origin, which are included within the malacological collection.

## SYSTEMATIC PALEONTOLOGY

DINOSAURIA Owen, 1842

SAURISCHIA Seeley, 1888

SAUROPODA Marsh, 1878

TITANOSAURIA Bonaparte and Coria, 1993

Gen. et sp. indet.

**Referred Specimen.** MSV.P19-3.1.1, proximal portion of a right ulna.

**Description and comparisons.** The specimen MSV.P19-3.1.1 corresponds to the proximal portion of a right ulna (Figs. 3A–D). The specimen measures 26 cm from the preserved diaphysis to the posterior process of the olecranon. The element has robust proportions, which is a feature observed in Saltosauridae, especially in *Neuquensaurus* and *Saltasaurus* (Wilson, 2002). In contrast, most other titanosaurs, such as *Mendozatitan* and *Narambuenasaurus*, have comparatively more gracile ulnas (González Riga et al., 2019). However, caution should be exercised with this feature, as robust ulnas have also been described in non-titanosaurian sauropods such as *Mamenchisaurus*, *Apatosaurus*, and *Hudiesaurus* (Upchurch et al., 2015).

As is typical of sauropods, the proximal surface of the specimen is slightly rugose, which represents the surface for cartilage attachment (Gorscak et al., 2023). As in all sauropods, in proximal view, the MSV.P19-3.1.1 shows a triradiate morphology (Salgado & Coria, 1993; Upchurch et al., 2015). Also, in proximal view (Fig. 4A) is observed that the anteromedial process is longer than the anterolateral process, which is a common condition in titanosaurs and sauropods in general (González Riga et al., 2019). This condition differs from the subequal anteromedial and

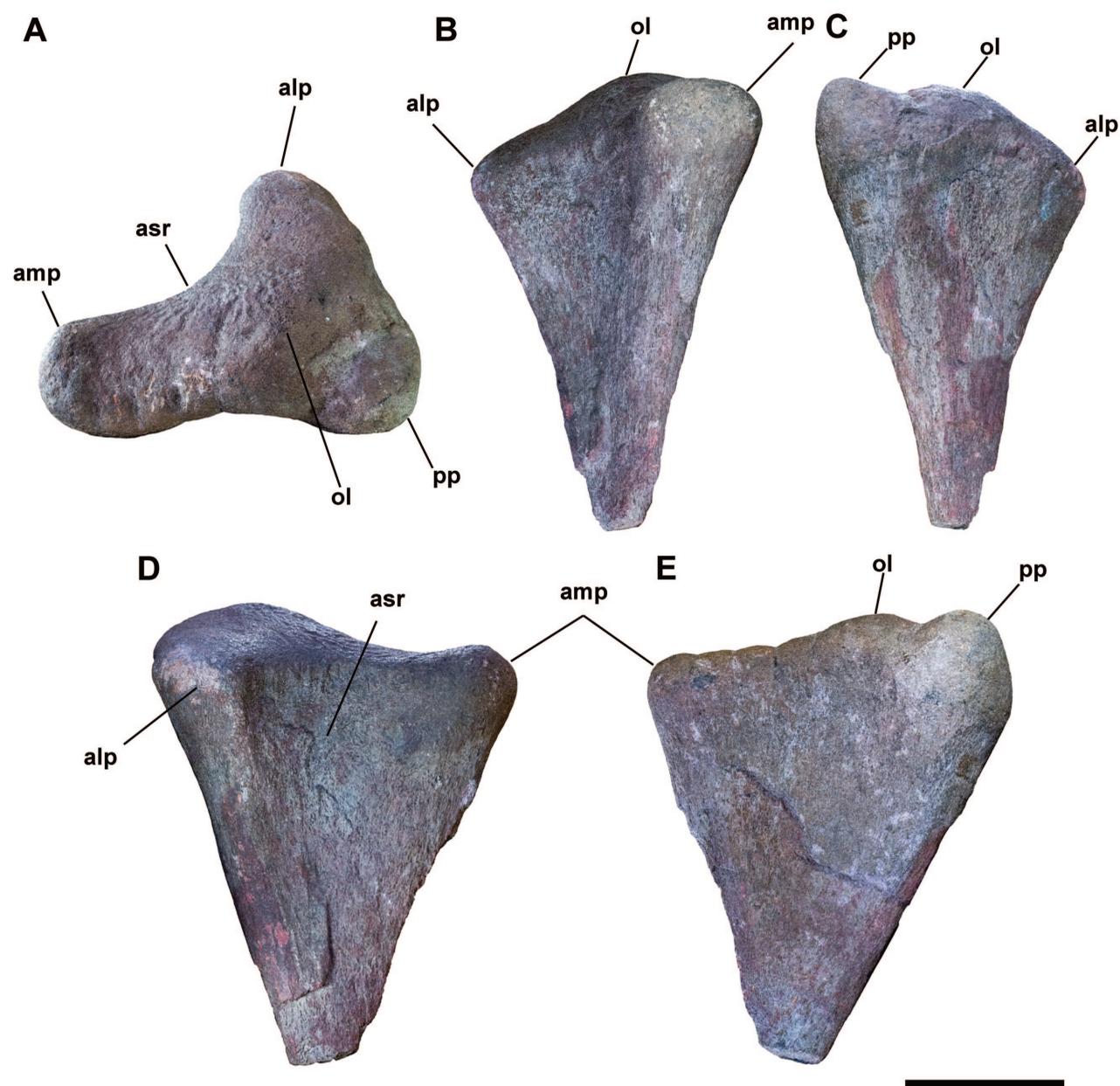
anterolateral processes of some diplodocoids and titanosauriforms (Wilson, 2002). Among the latter group, in taxa such as *Diamantinasaurus* the difference in length between the anterolateral and anteromedial processes is not as marked as it is in titanosaurs such as *Rapetosaurus*, *Patagotitan*, *Neuquensaurus*, and in the specimen studied in this work (Poropat et al., 2015; Figs. 4B, C, D). The anteromedial process is 1.38 times longer than the anterolateral process, being proportionally shorter than in Titanosauriformes as *Angolatitan* (Mateus et al., 2011), and then in titanosaurians as *Patagotitan* (D’Emic, 2012; Upchurch et al., 2015; Fig. 4C), but longer than in the titanosaurians *Saltasaurus*, *Dreadnoughtus* and *Diamantinasaurus* (Figs. 4E, F, G). This value is close to that of the turiasaurian *Zby atlanticus* Mateus et al., 2014, in which the anteromedial process is 1.29 times longer than the anterolateral process (Mateus et al., 2014).

The ratio of anteromedial process length to its minimum width is 3.2, which exceeds 2.5 a value also observed in the diplodocid *Diplodocus* and in the titanosaurs *Bonitasaura*, *Rapetosaurus*, and *Elaltitan* (Apesteguía, 2004; D’Emic, 2012; Upchurch et al., 2015; Otero et al., 2020). The anteromedial process of MSV.P19-3.1.1 is more robust than in the brachiosaurid *Vouivria* (Fig. 4H), in the Macronaria *Haestasaurus* (Fig. 4I), and that in the titanosaurians *Rapetosaurus* (Fig. 4B), and *Saltasaurus* (Fig. 4E). The angle formed between the anterolateral and anteromedial processes is approximately 104° (Fig. 3A). According to Upchurch et al. (2015), an angle greater than 80° is characteristic of Titanosauria, as seen in *Giraffatitan*, *Opisthocoelicaudia*, *Rapetosaurus*, and *Haestasaurus* (Janensch, 1961; Borsuk-Białyńska, 1977; Curry Rogers, 2009; Upchurch et al., 2015). This value is also close to that of the turiasaurian *Zby atlanticus*, whose angle is 110° (Mateus et al., 2014).

The olecranon is rounded and moderately developed (Figs. 3A, B, C, E). The reduced olecranon is a derived feature present in most sauropods like *Camarasaurus* (Wilson & Sereno, 1998) except for some titanosaurs (Upchurch, 1995, 1998; Wilson, 2002). This structure is located in a posterolateral position and extends slightly over the articular surface, as in Titanosauria (Otero, 2010; Hechenleitner et al., 2020). The olecranon in the specimen MSV.P19-3.1.1 is slightly more developed than in the titanosaurian

*Bustingorrytitan*, in which the olecranon is autapomorphically poorly developed (Simón & Salgado, 2023). The olecranon is more elevated than the anteromedial and anterolateral processes, but does not project above the proximal ulnar articulation. The latter is a feature present in early-diverging titanosauriforms such as *Giraffatitan* and *Sauroposeidon* (D’Emic, 2012; Mannion et al., 2013), as well as in derived forms as *Patagotitan* (Otero et al., 2020). Other titanosauri-

ans with a low but well-defined olecranon process are *Rapetosaurus*, *Magyarosaurus* and *Phuwiangosaurus* (Martin et al., 1999; Curry Rogers, 2009). In contrast, in the camarasaurid *Janeschia* and in the titanosaurians as *Dreadnoughtus*, *Neuquensaurus*, *Alamosaurus*, *Diamantinasaurus*, *Malawisaurus*, *Opisthocoelicaudia*, and *Saltasaurus* the olecranon is prominent (Gilmore, 1946; Borsuk-Białyńska, 1977; Upchurch, 1995; Gomani, 2005; Poropat et al., 2015; Upchurch et al.,

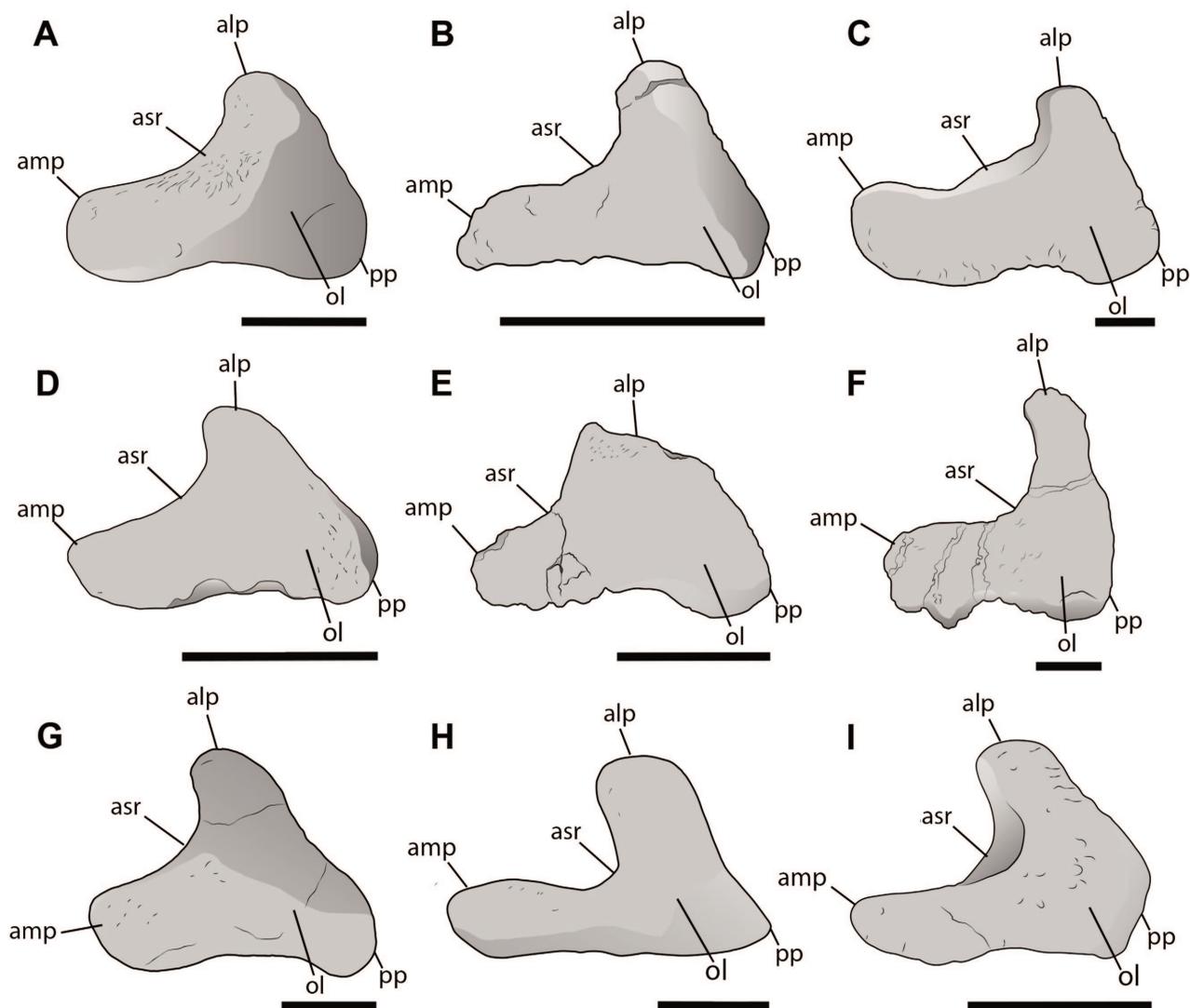


**Figure 3.** Proximal portion of right ulna (MSV.P19-3.1.1). A, in proximal. B, anterior. C, posterior. D, lateral. E, medial. Abbreviations: amp, anteromedial process; alp, anterolateral process; asr, articular surface for the radius; ol, olecranon; pp, posterior process of the olecranon. Scale= 10 cm.

2015; Ullmann & Lacovara, 2016; Otero, 2010, Otero et al., 2020).

The ulna described in this work shows several similarities to those of other described titanosaurians, especially from South America. However, it does not seem to correspond to any of the South American species named so far. The ulna of *Neuquensaurus australis* Lydekker, 1893 (MLP-CS 1306; Fig. 4C) is the most similar to the ulna MSV.P19-3.1.1, especially in its comparatively more robust

proportions than other titanosaurs, and in the possession of a prominent and robust posterior process of the olecranon, in addition to having a less deep articular surface for the radius compared to other Titanosauriformes (Figs. 4B–H). Other similarity is that, in the proximal view, MSV.P19-3.1.1 and the ulna of *Neuquensaurus* have a similar profile, mainly due to similar morphology and proportions of the anterolateral and anteromedial processes and a similar marked development of the posterior process of the



**Figure 4.** Comparison among Titanosauriformes ulnae in proximal view. A. MSV.P19-3.1.1, right ulna. B. *Rapetosaurus krausei* (FMNH PR 2209, left ulna, reversed). Drawing from Curry Rogers (2009). C. *Patagotitan mayorum* (MPEF-PV 3399/37, left ulna, reversed). Drawing from Otero et al. (2020). D. *Neuquensaurus australis* (MLP-CS 1306, left ulna, reversed). Drawing from Otero (2010). E. *Saltasaurus loricatus* (PVL 4017-74, left ulna, reversed). Drawing from photographs taken by Matías A. Armella and Pablo E. Ortiz. F. *Dreadnoughtus schrani* (MPM-PV 1156, left ulna, reversed). Drawing from Ullmann & Lacovara (2016). G. *Diamantinasaurus matildae* (AODF 603, right ulna). Drawing from Poropat et al. (2015). H. *Vouivria damparisensis* (MNHN.F.1934.6DAM30, left ulna, reversed). Drawing from Mannion et al. (2017). I. *Haestasaurus becklesii* (NHMUK R 1870, left ulna, reversed). Drawing from Upchurch et al. (2015). Abbreviations: amp, anteromedial process; alp, anterolateral process; asr, articular surface for the radius; ol, olecranon; pp, posterior process of the olecranon. Scale=10 cm.

olecranon. However, in the ulna of *Neuquensaurus australis*, the anterolateral and anteromedial processes are slightly less robust, and the anterolateral process is slightly more inclined anteriorly than in MSV.P19-3.1.1 (Fig. 4D). The specimen MSV.P19-3.1.1 also differs from the ulna of *Neuquensaurus* in that the olecranon of the latter is more developed than in the specimen described here. The contour of the specimen MSV.P19-3.1.1 in the proximal view also resembles *Patagotitan* (Fig. 4C). However, in the latter, the anterolateral process is smaller, the anteromedial process curves laterally, and the posterior process of the olecranon is more quadrangular. The profile of MSV.P19-3.1.1 is also similar to those of non-Titanosaurian Titanosauriformes such as *Angolatitan*, although in the latter the angle of the articular surface for the radius is less wide, and the anteromedial process is more constricted at its base and slightly wider at its tip (Mateus et al., 2011).

Based on our comparisons, the South American sauropod with the ulna most similar to specimen MSV.P19-3.1.1 is *Neuquensaurus*. The general similarity between the ulna MSV.P19-3.1.1 and the ulna of *Neuquensaurus australis* suggests that the specimen MSV.P19-3.1.1 belongs to a taxon that is phylogenetically close to that species.

## DISCUSSION

### Collection

Based on historical records, there was no dedicated paleontological collection at the Museo Seminario Valparaíso. For this reason, specimen MSV.P19-3.1.1 was found mixed among the larger specimens of the mineral collections, which contain labels dated between 1860 and 1896 (SONAMI, 1883-1918; Chirino-Gálvez et al., 2022). Additionally, as previously stated, the MSV collections have remained unaltered for over a century (Chirino & Vicencio, 2021; Chirino-Gálvez et al., 2022). This suggests that specimen MSV.P19-3.1.1 was likely deposited in the mineral collections no later than the early 20<sup>th</sup> century, when the institution ceased receiving donations and the collections were placed in storage at the MSV building.

### Provenance

The ulna specimen displays a reddish patina, characteristic of mineralization likely associated with

hematite (Bao et al., 1998). Microscopic analyses have shown that the surface adsorption of humic acids and metal ions is responsible for the coloration of fossil bones (Turner-Walker, 1993). This distinctive coloration and state of preservation, frequently observed in fossils, can be used to study and correlate colored mineral traces, along with other associated markers, to the surrounding rock matrix and to identify specimens from recorded localities (Tab. 1).

When considering the associated petrographic records from the Tolar Formation, Hornitos Formation, Dorotea Formation, Toqui Formation, and Totorá Strata, the only geological unit reporting lithic fragments (silicified tuffaceous, andesitic, ferruginous andesitic, and granodioritic), as well as silicified and clay-altered fragments and crystals (plagioclase, quartz, hematite-magnetite) cemented by zeolites or ferruginous material is the Albian-Turonian *Estratos de Quebrada La Totorá* in Pichasca, Coquimbo Region (Pineda & Emparan, 2006). In the *Estratos de Quebrada La Totorá*, fine-grained sandstones have been described, composed of crystals (feldspars, orthoclase and plagioclase, quartz, mafic minerals altered to chlorite and epidote, and magnetite-hematite) and lithic fragments, with a notable presence of hematite (Casamiquela et al., 1969; Pineda & Emparan, 2006; Amudeo-Plaza et al., 2023). These characteristics suggest that the fossil specimen most likely was found in rocks of this geological unit. However, this cannot be stated with complete certainty. Histological sections are suggested to try to resolve this issue, as they could provide more information on the trace minerals present in the specimen.

Information about the large fossil bone deposited in the MSV is minimal, primarily due to the limited knowledge of dinosaurs in Chile more than a century ago. It should be noted that the natural history teachers at this institution relied mainly on the natural history textbook used in Chile at the beginning of the century, which stated that “few fossil remains of reptiles” had been found in Chile (Philippi, 1877-93). This remark referred to a handful of large fossil reptile bones identified and preserved at the National Museum of Santiago before 1900. These consisted of fragmentary plesiosaur bones, also mentioned as objects of study, together with other unnamed fossil reptiles, in the official zoology curricula for Chilean secondary education

(Barros Arana, 1893). A second textbook, officially used in Chile as a reference for the Baccalaureate examinations in Natural History and widely known throughout Spanish America, included and illustrated terrestrial sauropod reptiles known at the time as sauropods, stegosaurs, and iguanodonts (Langlebert, 1906). It excluded the less mineralized fossils of Pleistocene macrofauna —such as mastodons, ground sloths, and fossil horses— which were more frequently recorded in Chilean collections and in fact, it was mandatory to be taught as Natural History subject, naming them along with the “Plesiosaur and other fossil reptiles” (Barros Arana, 1893).

To assess whether this dinosaur specimen is the oldest found in a Chilean collection, it is necessary to consider that only three museums have verified historical records of Chilean natural history collections, including fossils: the National Museum (1853), the Museum of Natural History of Valparaíso (1878), and the Museum of Natural History of Concepción (1902). The first museum to incorporate dinosaur remains into its collection was the National Museum of Natural History (MNHN, Santiago), which featured fossils discovered in Pichasca during the 1960s (Casamiquela et al., 1969). Based on records of mineral donations to the MSV (1896), it is suggested that the specimen described here predates those reported for the MNHN by a period of 70 years.

### Taxonomy of MSV.P19-3.1.1

Based on the available data, the specimen MSV.P19-3.1.1 (Fig. 4A) exhibits morphological features consistent with Titanosauriformes, specifically within the clade Titanosauria (Borsuk-Białynicka, 1977; Curry Rogers, 2009; Upchurch et al., 2015; González Riga et al., 2016; Otero et al., 2020). This group has been well documented in the Cretaceous of South America (e.g., Calvo & Bonaparte, 1991; Novas, 2009; González Riga et al., 2016; Otero et al., 2020; Fiorelli et al., 2022). The first discoveries of South American titanosaurs date back to the late 19<sup>th</sup> century in Argentina, specifically in the provinces of Neuquén and Santa Cruz (Lydekker, 1893; Ameghino, 1898), while the first findings of titanosaurs in Chile were made in the mid-20<sup>th</sup> century (Casamiquela et al., 1969).

Traditionally, the most important features used to

classify titanosaurs are those of the vertebral column, including the strongly procoelous nature of the anterior caudal vertebrae and six sacral vertebrae, along with other traits related to the centrum and neural arches (e.g., Carroll, 1988; Upchurch et al., 2015). However, additional features related to the limbs have recently been incorporated, such as the proportion of the anteromedial process of the ulna, which is a relatively new diagnostic trait (D’Emic, 2012). The specimen MSV.P19-3.1.1 showed proportions of the anteromedial process consistent with the condition described in several titanosaurs. The same was true for the angle between the anterolateral and anteromedial processes, which is within the range of Titanosauria. Additional characters that suggest that MSV.P19-3.1.1 belongs to Titanosauria concern the olecranon and anteromedial process. The specimen has a rounded olecranon that projects above the anterolateral and anteromedial processes, together with a concave anteromedial surface, allowing for full extension of the forelimb (Wilson & Sereno, 1998), which are characters that have been characterized in several titanosaurs (D’Emic, 2012; Upchurch et al., 2015; Otero et al., 2020).

Within Titanosauria, our comparisons showed that the specimen MSV.P19-3.1.1 is particularly similar to the ulna of *Neuquensaurus*, which suggest that the MSV.P19-3.1.1 specimen corresponds to the Lithostrotia clade. Additionally, both the ulna studied here and the ulnae of saltasaurids such as *Neuquensaurus* and *Saltasaurus* share robust proportions. These similarities suggest that MSV.P19-3.1.1 could have belonged to a titanosaur member of Saltosauridae. The latter should be taken with caution, as traits such as robustness are also present in non-titanosaurian sauropods (Upchurch et al., 2015).

Considering that records of titanosaur dinosaurs in Chile remain relatively scarce —with only two formally named species (*Atacamaitan chilensis* and *Arackar licanantay*), and additional partial discoveries in both northern and southern Chile (see Tab. 1 for a summary, and Figs. 1A, B)— any additional finding, such as the museum specimen described here, has the potential to provide novel information contributing to our understanding of the diversity and evolution of these taxa along the Pacific margin of South America.

## CONCLUSIONS

The mineralogical and paleontological collection housed at the Museo Seminario Valparaíso was deposited in the late 19<sup>th</sup> century and has remained unaltered there since the early 20<sup>th</sup> century. Considering that the first documented records of dinosaurs in Chile date to the 1960s, the specimen described in this work would represent the oldest dinosaur deposited in a Chilean museum. Regarding the description and comparisons of specimen MSV.P19-3.1.1, the evidence indicates that it corresponds to the right ulna of a sauropod. Furthermore, features such as the relative size of the anteromedial and anterolateral processes, its robustness, as well as the position of the olecranon, support its classification within the clade Titanosauria, possibly included in Saltasauridae. Additionally, the preservation of the specimen suggests that it could originate from the Pichasca Locality, Coquimbo region, specifically from the Albian–Turonian *Estratos de Quebrada La Totorá*. However, further analysis, such as histological sections, is needed to evaluate mineral traces in greater detail. Although fragmentary, the information on specimen MSV.P19-3.1.1 suggests that additional paleontological discoveries could be made in historical museums whose collections have been under-studied.

## ACKNOWLEDGMENTS

The authors thank Natalie Recabarren (MSV, Seminario San Rafael) for her curatorial support and for facilitating the study of specimen MSV.P19-3.1.1. Appreciation is further extended to Pablo E. Ortiz (Curator of the Vertebrate Paleontology Collection Lillo, PVL) and Matías A. Armella (INSUGEO) for providing photographs and anatomical data regarding the ulna of *Saltasaurus lorricatus* (PVL 4017-74), housed at the Instituto Miguel Lillo, Universidad Nacional de Tucumán, Argentina. JAM was supported by ANID scholarships for PhD studies in Chile.

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doi: 10.5710/PEAPA.08.12.2025.555

**Recibido:** 26 de septiembre 2025

**Aceptado:** 8 de diciembre 2025

**Publicado:** 13 de marzo 2026



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